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ABSTRACT

This chapter focuses on a particular type of classroom teaching experiment that is conducted in collaboration with a practicing teacher. The first section discusses the theoretical orientation that underpins this methodology and outlines the types of problems that are addressed in the course of a classroom teaching experiment. The three central aspects of this methodology in the context of developmental research include instructional design and planning, the ongoing analysis of classroom events, and the retrospective analysis of all the data sources generated in the course of a teaching experiment. Against this background attention is given to specific methodological issues, among them generalizability, trustworthiness, and commensurability. Finally, the process of establishing collaborative relationships with teachers is reviewed and the chapter concludes by discussing problems for which other methodologies might be more appropriate. (KHR)

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The past decade has witnessed a number of profound shifts in the ways in which the problems and issues of mathematics education have been framed and addressed. The first of these shifts concerns the characterization of individual students' mathematical activity. The central metaphor of students as processors of information has been displaced by that of students acting purposefully in an evolving mathematical reality of their own making (Sfard, 1994). As a consequence, analyses of students' mathematical reasoning have moved away from specifying cognitive behaviors and toward inferring the quality of their mathematical experience. A second shift concerns the increased acknowledgment of the social and cultural aspects of mathematical activity (Nunes, 1992; Voigt, 1994). As recently as 1988, Eisenhart could write with considerable justification that mathematics educators "are accustomed to assuming that the development of cognitive skill is central to human development, [and] that these skills appear in a regular sequence regardless of context or content" (p. 101). The growing trend to go beyond a purely cognitive focus is indicated by an increasing number of analyses that question an exclusive preoccupation with the individual learner (Cobb & Bauersfeld, 1995; Greeno, 1991; Lave, 1988; Saxe, 1991; Whitson, in press). In this emerging view, individual students' activity is seen to be located both within the classroom microculture and within broader systems of activity that constitute the sociopolitical setting of reform in mathematics education.

A third shift in suppositions and assumptions concerns the relation between theory and practice. In traditional approaches that embody the positivist epistemology of practice, theory is seen to stand apart from and above the practice of learning and teaching mathematics

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(Schön, 1983). Then teachers are positioned as consumers of research findings that are generated outside the context of the classroom. In contrast to this subordination of practice to theory, an alternative view is emerging that emphasizes the reflexive relationship between the two (Gravemeijer, 1995). From this latter perspective, theory is seen to emerge from practice and to feed back to guide it. This view, it should be noted, provides a rationale for transformational research that has as its goal the development and investigation of theoretically grounded innovations in instructional settings. Taken together, these shifts in the ways in which problems of teaching and learning mathematics are cast have precipitated the development of a range of new methodologies, many of which are discussed in this volume. The focus in this chapter is on a particular type of classroom teaching experiment that is conducted in collaboration with a practicing teacher who is a member of the research and development team. Experiments of this type can vary in duration from a few weeks to an entire school year and typically have as one of their goals the development of instructional activities for students. The concerns and issues discussed by the research team while the experiment is in progress are frequently highly pragmatic in that the teacher and the researchers are responsible together for the quality of the students' mathematics education. As a consequence, initial conjectures typically emerge while addressing specific practical issues. These conjectures later orient a retrospective analysis of data sources that can include videorecordings of classroom sessions, videorecorded interviews conducted with the students, copies of the students' written work, daily field notes, records of project meetings and debriefing sessions, and the teacher's daily journal.

In the following sections of the chapter, I first discuss the theoretical orientation that underpins this methodology and outline the types of problems that might be addressed in the course of a classroom teaching experiment. Then, I place the methodology in the context of developmental research and consider three central aspects of the approach: instructional design and planning, the ongoing analysis of classroom events, and the retrospective analysis of all the data sources generated in the course of a teaching experiment. Against this background, attention is given to specific methodological issues, among them generalizability, trustworthiness, and commensurability. Finally, I focus on the process of establishing collaborative relationships with teachers and conclude by discussing problems for which other methodologies might be more appropriate.

THEORETICAL ORIENTATION

As M. Simon (1995) observed, several different forms of constructivism have been proposed in recent years. A key issue that differentiates these positions is the relationship between individual psychological processes and classroom social processes. At one extreme, researchers who take a strong psychological perspective acknowledge the influence of social interaction, but treat it as a source of perturbations for otherwise autonomous conceptual development. Such approaches recognize that the *process* of students' mathematical development has a social aspect in that interpersonal interactions serve as a catalyst for learning. However, the *products* of development—students' increasingly sophisticated mathematical ways of knowing—are treated exclusively as individual psychological accomplishments. At the other extreme, sociocultural approaches in the Vygotskian tradition tend to elevate social processes above psychological processes. For example, it is argued in some formulations that the qualities of students' mathematical thinking are *generated by* or *derived from* the organizational features of the social activities in which they participated (van Oers, 1996). Such approaches account for development primarily in social terms and leave little room for psychological analyses of individual students' constructive activities.

The theoretical stance that underpins the type of classroom teaching experiment I discuss should be distinguished from both strong psychological and strong social versions of constructivism. This alternative stance has been called the emergent perspective (Cobb, 1995). One of its central assumptions is that learning can be characterized as both a process of active individual construction and a process of mathematical enculturation (cf. Dorfler, 1995). On the one hand, the emergent perspective goes beyond exclusively psychological approaches by viewing students' mathematical activity as being necessarily socially situated. Therefore, the products of students' mathematical development—increasingly sophisticated ways of reasoning—are seen to be related to their participation in particular communities of practice such as those constituted by the teacher and the students in the classroom. On the other hand, the emergent perspective questions the subordination of psychological processes to social processes and attributes a central role to analyses of individual students' mathematical activity. The basic relationship posited between students' constructive activities and the social processes in which they participate in the classroom is one of reflexivity in which neither is given preeminence over the other. In this view, students are considered to contribute to the

evolving classroom mathematical practices as they reorganize their individual mathematical activities. Conversely, the ways in which they make these reorganizations are constrained by their participation in the evolving classroom practices. A basic assumption of the emergent perspective is, therefore, that neither individual students' activities nor classroom mathematical practices can be accounted for adequately except in relation to the other.

It should be noted that this view of mathematical learning as a participatory activity has immediate pragmatic implications for the conduct of teaching experiments. For example, if one wants to investigate students' development of what the National Council of Teachers of Mathematics (1991b) called a mathematical disposition, then it is crucial that they participate in classroom mathematical practices in which they are expected to judge what counts as acceptable mathematical explanations and as different, efficient, and sophisticated mathematical solutions (Lampert, 1990; Yackel & Cobb, 1996). Similarly, if one wants to investigate how students might come to use conventional and nonstandard notations in powerful ways, then it is important to document the ways in which they participate in practices that involve the development of ways of recording mathematical activity for communicative purposes (Bednarz, Dufour-Janvier, Porrier, & Bacon, 1993; van Oers, 1995).

Theoretically, the emergent perspective emphasizes the importance of analyzing students' mathematical activity as it is situated in the social context of the classroom. Therefore, accounts of their mathematical development might involve the coordination of psychological analyses of their individual activities with social analyses of the norms and practices established by the classroom community. The particular psychological perspective that I and my colleagues adopt is broadly compatible with that outlined by other contributors to this volume (cf. Steffe & Thompson, chap. 11, this volume). The social perspective draws on symbolic interactionism and ethnomethodology as they have been adapted to the problems and issues of mathematics education (Bauersfeld, Krummheuer, & Voigt, 1988). Discussion of this perspective can be found in Bauersfeld (1988) and Voigt (1994).

In a subsequent section of this chapter, I clarify the relationship between these two perspectives while outlining an interpretive framework for analyzing individual and collective mathematical activity in the classroom. For the present, my concern is to emphasize the more general point that classroom teaching experiment methodology requires a way of relating individual students' mathematical activity to the local social world of the classroom in which they participate. In my view, teaching experiments that fail to acknowledge this theoretical issue are suspect. Almost by default, analyses are produced in which mathematical

development seems either to occur in a social vacuum or to be attributed directly to social processes. The emergent perspective I have outlined constitutes one way of relating social and psychological analyses.[1] As becomes clear, this perspective itself emerged while conducting a series of teaching experiments in the classroom. Its focus on mathematical activity in a social context provides a strong rationale for developing classrooms as action research sites.

Problems and Issues

Classroom teaching experiments have a relatively long history in mathematics education, particularly in the former Soviet Union (Davydov, 1988). However, the particular type of classroom teaching experiment with which I am concerned evolved most directly from the constructivist teaching experiment (Cobb & Steffe, 1983; Steffe, 1983; see also Steffe & Thompson, chap. 11, this volume). In the constructivist teaching experiment, the researcher acts as teacher and usually interacts with students either one-on-one or in small groups. As Steffe and Thompson explain in chapter 11 in this book, the researcher's primary goal "is to establish a *living model* of children's mathematical activity and transformations of this activity as a result of mathematical interactions in learning environments." The decision that I and my colleagues[2] made to extend this approach to the classroom was precipitated by investigations that documented the undesirable mathematical beliefs and conceptions that students typically develop in the context of traditional instruction (e.g., Carraher & Schliemann, 1985; Schoenfeld, 1983). The initial issue the classroom teaching experiment was designed to address was that of investigating students' mathematical learning in alternative classroom contexts developed in collaboration with teachers. The methodology therefore provides a way of exploring the prospects and possibilities for reform at the

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[1] The emergent goals model developed by Saxe (1991) represents an alternative, though broadly compatible, approach that deals with both individual and collective processes.

[2] The type of teaching experiment described in this chapter was developed initially in collaboration with Erna Yackel and Terry Wood. More recent modifications have been made in collaboration with Erna Yackel and Koeno Gravemeijer. Where appropriate, I use the first-person plural throughout the chapter to indicate these collaborations.

classroom level. This focus on students' mathematical development immediately leads to a number of related issues. The first of these concerns the social context of development. The classroom microculture in which students participate influences profoundly the goals they attempt to achieve, their understanding of what counts as an acceptable mathematical explanation, and, indeed, their general beliefs about what it means to know and do mathematics in school. Consequently, it is essential to document the microculture established by the classroom community even if the primary concern is to formulate psychological models of the processes by which students transform their mathematical activity. However, beyond this minimalist approach, aspects of the classroom microculture (and students' participation in it) can become legitimate objects of inquiry. For example, analyses might be conducted that focus on the teacher's and students' negotiation of general classroom social norms, standards of mathematical argumentation, or particular classroom mathematical practices. Further, teaching experiments can be conducted to investigate the extent to which students' participation in particular social arrangements such as small-group, collaborative activity or whole-class discussions supports their mathematical development.

A second cluster of related issues that are appropriate for investigation centers on the activity of the teacher. It is generally acknowledged that the classroom is the primary learning environment for teachers as well as for students and researchers (Ball, 1993b; Cobb, T. Wood, & Yackel, 1990; Knapp & Peterson, 1995; M. Simon & Schifter, 1991; A. Thompson, 1992). In particular, it appears that teachers reorganize their beliefs and instructional practices as they attempt to make sense of classroom events and incidents. Hence, teachers' learning, as it occurs in a social context, can become a direct focus of investigation in a teaching experiment.[3]

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[3] In chapter 9 in this book, Lesh and Kelly describe a three-tiered teaching experiment in which the tiers or levels focus on the students, the teachers, and the researchers respectively. The classroom teaching experiment methodology outlined in this chapter can be used to investigate students' and teachers' learning as it occurs in a social context. Such investigations are located at the lower two tiers of Lesh and Kelly's model. However, the teaching experiment methodology is not well suited to the problem of analyzing systematically the researchers' learning as it occurs in a social context. An adequate treatment of this issue would require a second group of researchers who study

(continued)

Additionally, it should be noted that teachers who participate in teaching experiments typically become extremely effective in supporting their students' mathematical development. This, therefore, constitutes an opportunity to delineate aspects of effective reform teaching as they are manifested in the teachers' interactions with their students. Analyses of this type can make an important contribution in that reform teaching often is characterized with reference to traditional instruction, and the emphasis is on what teachers should not do. In my view, there is a pressing need to clarify further how teachers support their students' mathematical development *proactively* as they act and interact in the social context of the classroom.

A third set of issues that might be addressed by conducting a classroom teaching experiment centers on the development of instructional sequences and the local, domain-specific instructional theories that underpin them (Gravemeijer, 1995). In the course of a classroom teaching experiment, the research team develops sequences of instructional activities that embody conjectures about students' constructive activities. An analysis of students' learning in a social context requires that the instructional activities be documented as they are realized in interaction. This analysis can be used to guide both the revision of the instructional activities and the elaboration of their rationale in terms of students' potential construction in the social situation of the classroom. I discuss the process of instructional development in more detail in the next section of this chapter. For the present, it suffices to note that if this cyclic process of design and analysis is repeated a number of times, the rationale can be refined until it acquires eventually the status of a local instructional theory that underpins an instructional sequence (Gravemeijer, 1995). Streefland's (1991) analysis of a

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the first group working with students and teachers. (An example of an outside analysis of this type in which I and my colleagues became subjects was reported by Dillon, 1993.) Nonetheless, the research team conducting a classroom teaching experiment does compile a record of its own learning in the spirit of Lesh and Kelly. Typically, this documentation includes audiorecordings of project meetings as well as paper documentation. Further, the researchers attempt to remain aware that their activity is, like that of the teachers, socially situated and that the products of the research are grounded in their classroom-based practice. I attempt to indicate this sense of situation throughout the chapter.

series of teaching experiments that focused on students' understanding of fractions is paradigmatic in this regard.

A final set of issues for which the teaching experiment methodology is appropriate is located at a metalevel and concerns the development of theoretical constructs that might be used to make sense of what is going on in the classroom. When discussing the theoretical orientation, I noted that the emergent perspective itself emanated from a series of teaching experiments. The viewpoint that I and my colleagues held at the outset was primarily psychological in that we intended to focus on the conceptual reorganizations that individual students made while interacting with their peers and the teacher. However, it soon became apparent that a psychological perspective, by itself, was inadequate to account for students' mathematical activity in the classroom. Thus, it was while trying to make sense of what was happening in classrooms that we revised a number of our basic assumptions and formulated the goal of developing a complementary social perspective. The delineation of this global objective was, however, merely a first step. It is one thing to make general pronouncements about the coordination of psychological and social perspectives and another to conduct empirical analyses of classroom events based on this intention. A fundamental issue that we have addressed while conducting teaching experiments is that of developing theoretical constructs that are tailored to our needs as mathematics educators interested in reform at the classroom level. One of the strengths of the classroom teaching experiment methodology is that it makes it possible to address both pragmatic and highly theoretical issues simultaneously. It is in this sense that the methodology enacts the reflexivity between theory and practice.

TEACHING EXPERIMENTS IN THE CONTEXT OF DEVELOPMENTAL RESEARCH

In broad outline, the process of conducting a classroom teaching experiment can be characterized by the developmental research cycle as described by Gravemeijer (1995). As can

be seen from FIG. 12.1, this cycle consists of two general, closely related aspects.[4] The first focus is concerned with instructional development and planning and is guided by an evolving instructional theory. The second aspect involves the ongoing analysis of classroom activities and events, and is guided by an emerging interpretive framework. This cycle proves to be analogous in many ways to the mathematics teaching cycle developed by M. Simon (1995) and shown in simplified form in FIG. 12.2. In the following paragraphs, I draw heavily on M. Simon's analysis as I consider the two aspects of the developmental research cycle.

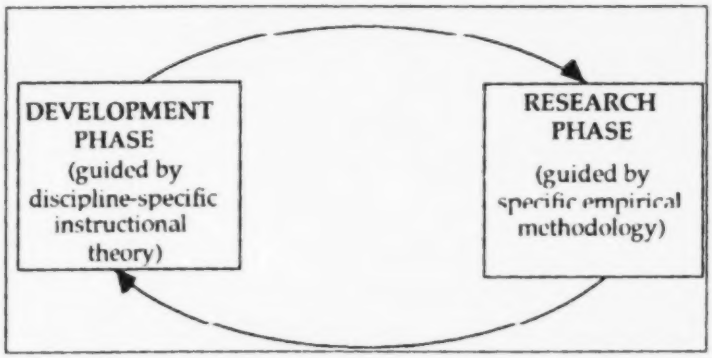

FIG. 12.1. Aspects of the developmental research cycle.

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[4]As becomes apparent, this cycle occurs at two distinct levels (Gravemeijer, 1995). The most basic is the microlevel, where the anticipatory thought experiment and the teaching experiment concern the planning and trying out of instructional activities on a day-to-day basis. At this level, the analysis of what happens in the classroom informs the planning of the next instructional activity to be enacted in the same classroom. At a second broader level, the developmental research cycle centers on an entire instructional sequence. The thought experiment at this level concerns the local instructional theory that underlies the sequence, and the teaching experiment involves the realization of the whole set of instructional activities in the classroom, even as they are being revised continually. This broader cycle builds on the learning process of the research team inherent in the daily microcycles and is complemented by a retrospective analysis of the entire data set generated in the course of the teaching experiment.

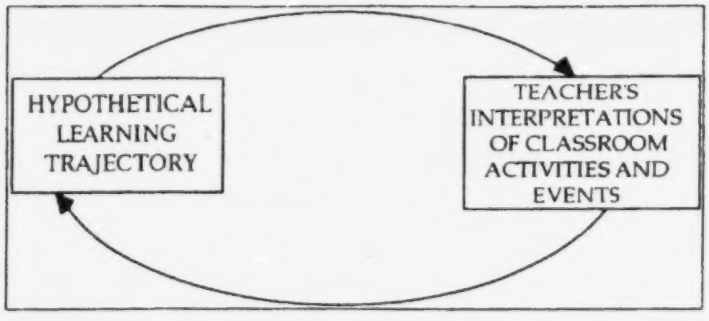

FIG. 12.2. A simplified version of M. Simon's (1995) mathematics teaching cycle.

Instructional Design and Planning

A classroom teaching experiment typically begins with the clarification of mathematical learning goals and with a thought experiment in which the research team envisions how the teaching–learning process might be realized in the classroom (Gravemeijer, 1995). In M. Simon's (1995) terms, this first step involves the formulation of a hypothetical learning trajectory that is made up of three components: learning goals for students, planned learning or instructional activities, and a conjectured learning process in which the teacher anticipates how students' thinking and understanding might evolve when the learning activities are enacted in the classroom. This approach acknowledges the importance of listening to students and attempting to assess their current understandings, but also stresses the importance of anticipating the possible process of their learning as it might occur when planned but revisable instructional activities are enacted in an assumed classroom microculture. In this approach:

> The development of a hypothetical learning process and the development of the learning [or instructional] activities have a symbiotic relationship; the generation of ideas for learning activities is dependent on the teacher's hypotheses about the development of students' thinking and learning; further, the generation of hypotheses of student conceptual development depends on the nature of anticipated activities. (M. Simon, 1995, p. 136)

This formulation implies that even if social processes in the classroom remain implicit, purely psychological analyses that characterize learning independent of situation are inadequate when designing and planning for instruction. What is required is an *instructional theory*,

however tentative and provisional, that gives rise to conjectures about possible means of supporting students' reorganization of their mathematical activity. A theory of this type embodies positive heuristics for the process of supporting students' development that have emerged in the course of prior teaching experiments conducted by both a particular research group and the research community more generally (Gravemeijer, 1995).[5] In my view, anticipatory heuristics of this type are particularly critical when the instructional activities involve technology-intensive learning environments such as microworlds in that it is frequently difficult to make substantial modifications once the teaching experiment is in progress.

The particular instructional theory that I and my colleagues have drawn on in recent classroom teaching experiments is that of *realistic mathematics education* (RME), developed at the Freudenthal Institute (Gravemeijer, 1995; Streefland, 1991; Treffers, 1987). In the following pages, I outline the tenets of this evolving theory to illustrate the importance of going beyond a purely psychological analysis when planning teaching experiments and designing instructional activities. As background, it should be noted that RME is broadly compatible with the emergent perspective in that both are based on similar characterizations of mathematics and mathematical learning (Cobb, Gravemeigher, Yackel, McClain, & Whitenack, in press). In particular, both contend that mathematics is a creative human activity and that mathematical learning occurs as students develop effective ways to solve problems and cope with situations. Further, both propose that mathematical development involves the bringing forth of a mathematical reality (Freudenthal, 1991). In social terms, this can be viewed as a process of enculturation into a historically evolving, interpretive stance (cf. Greeno, 1991; Saxe & Bermudez, 1996). In psychological terms, it involves the internalization and interiorization of mathematical activity by a process of reflective

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[5] Gravemeijer (1995) argued that the development of an instructional theory of this type involves a third cyclic process that is more distanced from classroom practice than either the daily microcycles or the cycles that center on entire instructional sequences. At this macrolevel, an instructional theory is generated by generalizing from local instructional theories that underpin specific instructional sequences. In this case, the empirical grounding of the evolving instructional theory is mediated by the developmental research cycles at the lower levels.

abstraction so that the results of activity can be anticipated and activity itself becomes an entity that can be manipulated conceptually (Sfard, 1991; P. W. Thompson, 1994b; von Glasersfeld, 1991a).

One of the central tenets of RME is that the starting points of instructional sequences should be experientially real to students in the sense that they can engage immediately in personally meaningful mathematical activity (Streefland, 1991). In this regard, P. W. Thompson (1992) noted from the emergent perspective that:

> If students do not become engaged imaginistically in the ways that relate mathematical reasoning to principled experience, then we have little reason to believe that they will come to see their worlds outside of school as in any way mathematical. (p. 10)

As a point of clarification, it should be stressed that the term *experientially real* means only that the starting points should be experienced as real by the students, not that they have to involve realistic situations. Thus, arithmetic tasks presented by using conventional notation might be experientially real for students for whom the whole numbers are mathematical objects. In general, conjectures about the possible nature of students' experiential realities are derived from psychological analyses. It also can be noted that even when everyday scenarios are used as starting points, they necessarily differ from the situations as students might experience them out of school (Lave, 1993; Walkerdine, 1988). To account for students' learning, therefore, it is essential to delineate the scenario as it is constituted interactively in the classroom with the teacher's guidance.

A second tenet of RME is that in addition to taking account of students' current mathematical ways of knowing, the starting points should be justifiable in terms of the potential endpoints of the learning sequence. This implies that students' initially informal mathematical activity should constitute a basis from which they can abstract and construct increasingly sophisticated mathematical conceptions as they participate in classroom mathematical practices. At the same time, the situations that serve as starting points should continue to function as paradigm cases that involve rich imagery and thus anchor students' increasingly abstract mathematical activity. This latter requirement is consistent with analyses that emphasize the important role that analogies (Clement & D. E. Brown, 1989), metaphors (Pimm, 1987; Presmeg, 1992; Sfard, 1994), prototypes (Dorfler, 1995), intuitions (Fischbein, 1987), and generic organizers (Tall, 1989) play in mathematical activity.

In dealing with the starting points and potential endpoints, the first two tenets of RME hint at the tension that is endemic to mathematics teaching. Thus, Ball (1993b) observed that recent American proposals for educational reform "are replete with notions of 'understanding' and 'community'—about building bridges between the experiences of the child and the knowledge of the expert" (p. 374). She then inquired:

> *How* do I [as a mathematics teacher] create experiences for my students that connect with what they now know and care about but that also transcend the present? *How* do I value their interests and also connect them to ideas and traditions growing out of centuries of mathematical exploration and invention? (p. 375.)

RME's attempt to cope with this tension is embodied in a third tenet wherein it is argued that instructional sequences should contain activities in which students create and elaborate symbolic models of their informal mathematical activity. This modeling activity might entail making drawings, diagrams, or tables, or it could entail developing informal notations or using conventional mathematical notations. This third tenet is based on the psychological conjecture that, with the teacher's guidance, students' *models of* their informal mathematical activity can evolve into *models for* increasingly abstract mathematical reasoning (Gravemeijer, 1995). Dorfler (1989) made a similar proposal when he discussed the role of symbolic *protocols of action* in enabling reflection on and analysis of mathematical activity. Similarly, Kaput (in press) suggested that such records and notations might support the taking of activities or processes as entities that can be compared and can come to possess general properties. To the extent that this occurs, students' models would provide eventually what Kaput (1991) termed semantic guidance rather than syntactic guidance. In social terms, this third tenet implies a shift in classroom mathematical practices such that ways of symbolizing developed to initially express informal mathematical activity take on a life of their own and are used subsequently to support more formal mathematical activity in a range of situations.

A discussion of RME as it relates to the design of instructional sequences involving technology-intensive learning environments was provided by Bowers (1995). It is apparent that the interpretation of RME I have given implies conjectures about both individual and collective development. For example, the speculation that students' models of their informal mathematical activity might take on a life of their own and become models for increasingly abstract mathematical reasoning implies conjectures about the ways in which they might reorganize their mathematical activity. Further, this conjecture about individual development

is made against the background of conjectures about the nature of the mathematical practices in which students might participate in the classroom, and about the ways in which those practices might evolve as students reorganize their activity. In general, conjectures of this type provide an initial orientation when planning a teaching experiment and designing instructional activities. However, the activities are modified continually in the course of the teaching experiment, and it is to this issue that I turn next.

Experimenting in the Classroom

As a pragmatic matter, it is critical in our experience that the researchers be present in the classroom every day while the teaching experiment is in progress. We also have found that short, daily, debriefing sessions conducted with the collaborating teacher immediately after each classroom session are invaluable. In addition, longer weekly meetings of all members of the research team, including the teacher, have proved essential. A primary focus in both of these meetings and the short debriefing sessions is to develop, consensual or "taken-as-shared" interpretations of what might be going on in the classroom. These ongoing analyses of individual children's activity and of classroom social processes inform new thought experiments in the course of which conjectures about possible learning trajectories are revised frequently. As a consequence, there is often an almost daily modification of local learning goals, instructional activities, and social goals for the classroom participation structure. Therefore, we have found it counterproductive to plan the details of specific instructional activities more than a day or two in advance.

This emphasis on an ongoing process of experimentation is compatible with M. Simon's (1995) observation that "the only thing that is predictable in teaching is that classroom activities will not go as predicted" (p. 133). He also noted that ideas and conjectures are modified as one attempts to make sense of the social constitution of classroom activities. In this view, the emerging interpretive framework that guides the researchers' sense-making activities is of central importance and influences profoundly what can be learned in the course of a teaching experiment. Therefore, it is important that the research team articulate a provisional framework before the teaching experiment commences by clarifying theoretical constructs that might be used to make sense of what is happening in the classroom. The framework that my colleagues and I use currently is shown in Table 12.1. As was the case when discussing RME, my intent in outlining the framework is to provide an illustrative example.

TABLE 12.1

An Interpretive Framework for Analyzing Individual and Collective Activity at the Classroom Level

Social Perspective	*Psychological Perspective*
Classroom social norms	Beliefs about our own role, others' roles, and the general nature of mathematical activity
Sociomathematical norms	Specifically mathematical beliefs and values
Classroom mathematical practices	Mathematical conceptions and activity

The framework can be viewed as a response to the issue of attempting to understand mathematical learning as it occurs in the social context of the classroom. I want to avoid the claim that the framework might capture somehow the structure of individual and collective activity independently of history, situation, and purpose. The most that is claimed is that it has proved useful when attempting to support change at the classroom level.[6] With regard to the specifics of the framework, the column headings "Social Perspective" and "Psychological Perspective" refer to the two, reflexively related perspectives, that together, comprise the emergent viewpoint. Recall that these are an interactionist perspective on communal classroom processes and a psychological constructivist perspective on individual students' (or the teacher's) activity as they participate in and contribute to the development of these collective processes. In the following paragraphs, I discuss classroom social norms first, then sociomathematical norms, and finally classroom mathematical practices.

Classroom Social Norms. As has been noted, the theoretical stance that underpinned the first classroom teaching experiment my colleagues and I conducted was primarily psychological. However, an unanticipated issue arose in the first few days of the school year. The second-grade teacher with whom we cooperated engaged her students in both collaborative, small-group work and whole-class discussions of their mathematical interpretations and solutions. It soon became apparent that the teacher's expectation that the children would

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[6] An elaboration of the framework that takes account of school-level and societal-level processes was discussed by Cobb and Yackel (1995).

explain publicly how they had interpreted and solved instructional activities ran counter to their prior experiences of class discussions in school. The students had been in traditional classrooms during their first-grade year and seemed to take it for granted that they were to infer the response the teacher had in mind rather than to articulate their own understandings. The teacher coped with this conflict between her own and the students' expectations by initiating a process that we came to term subsequently the renegotiation of classroom social norms. Examples of norms for whole-class discussions that became explicit topics of conversation include explaining and justifying solutions, attempting to make sense of explanations given by others, indicating agreement and disagreement, and questioning alternatives in situations where a conflict in interpretations or solutions has become apparent. In general, social norms can be seen to delineate the classroom participation structure (Erickson, 1986; Lampert, 1990).

A detailed account of the renegotiation process was given elsewhere (Cobb, Yackel, & Wood, 1989). For current purposes, it suffices to note that a social norm is not a psychological construct that can be attributed to a particular individual, but is instead a joint social construction. This can be contrasted with accounts framed in individualistic terms in which the teacher is said to establish or specify social norms for students. To be sure, the teacher is an institutionalized authority in the classroom (Bishop, 1985). However, from the emergent perspective, the most the teacher can do is express that authority in action by initiating and guiding the renegotiation process. The students also have to play their part in contributing to the establishment of social norms. A central premise of the interpretive framework is that in making these contributions, students reorganize their individual beliefs about their own role, others' roles, and the general nature of mathematical activity (Cobb et al., 1989). As a consequence, these beliefs are taken to be the psychological correlates of the classroom social norms (see Table 12.1).

Sociomathematical Norms. The analysis of general classroom social norms constituted our initial attempt to develop a social perspective on classroom activities and events. One aspect of the analysis that proved disquieting was that it was not specific to mathematics, but applied to almost any subject matter area. For example, one would hope that students would challenge each other's thinking and justify their own interpretations in science and literature lessons as well as in mathematics lessons. As a consequence, the focus of subsequent analyses shifted to the normative aspects of whole-class discussions that are specific to students' mathematical activity (Lampert, 1990; Voigt, 1995; Yackel & Cobb, 1996). Examples of

such sociomathematical norms include what counts as a different mathematical solution, a sophisticated mathematical solution, an efficient mathematical solution, and an acceptable mathematical explanation and justification.

The relevance of the first of these norms—that concerning mathematical difference—became apparent when attention was given to the process by which the collaborating teachers guided the development of an inquiry approach to mathematics in their classrooms. As a part of this process, the teachers asked the students regularly if anyone had solved a task a different way and then questioned contributions that they did not consider to be mathematically different. The analysis indicated that the students did not know what would constitute a mathematical difference until the teacher and other students accepted some of their contributions but not others. Consequently, in responding to the teacher's requests for a different solution, the students were both learning what counts as a mathematical difference and helping to establish what counts as a mathematical difference in their classroom. In the course of these interactions, the sociomathematical norm of mathematical difference emerged through a process of (often implicit) negotiation. The analysis of this norm has proven to be paradigmatic in that a similar process of development appears to hold for other sociomathematical norms such as those dealing with sophisticated and efficient solutions and with acceptable explanations and justifications (Yackel & Cobb, 1996).

It also is worth noting that the process of negotiating sociomathematical norms can give rise to learning opportunities for teachers as well as for students. For example, the teachers with whom we worked were attempting to develop an inquiry form of practice for the first time and had not, in their prior years of teaching, asked students to explain their thinking. Consequently, the experiential basis from which they attempted to anticipate students' contributions to classroom discussions was extremely limited. Further, they had not decided necessarily in advance what would constitute a mathematical difference or an acceptable justification. Instead, they seemed to explicate and elaborate their own understanding of these and other normative aspects of mathematical activity as they interacted with their students.

The analysis of sociomathematical norms has proved to be significant pragmatically when conducting teaching experiments in that it clarifies the process by which the collaborating teachers fostered the development of intellectual autonomy in their classrooms. In particular, these teachers attempted to guide the development of a community of validators in the classrooms by encouraging the devolution of responsibility (cf. Brousseau, 1984). However, students could assume these responsibilities only to the extent that they developed

personal ways of judging that enabled them to know both when it was appropriate to make a mathematical contribution and what constituted an acceptable contribution. This required, among other things, that the students could judge what counted as a different mathematical solution, an insightful mathematical solution, an efficient mathematical solution, and an acceptable mathematical explanation and justification. These are precisely the types of judgments that they and the teacher negotiated when establishing sociomathematical norms. This suggests that students constructed specifically mathematical beliefs and values that enabled them to act as increasingly autonomous members of classroom mathematical communities as they participated in the negotiation of sociomathematical norms (Yackel & Cobb, 1996). These beliefs and values, it should be noted, are psychological constructs and constitute a mathematical disposition (National Council of Teachers of Mathematics, 1991b). As shown in Table 12.1, they are taken to be the psychological correlates of the sociomathematical norms.

Classroom Mathematical Practices. The third aspect of the interpretive framework—concerning classroom mathematical practices—was motivated by the realization that one can talk of the mathematical development of a classroom community as well as of individual children. For example, in the second-grade classrooms in which my colleagues and I have worked, various solution methods that involve counting by ones are established mathematical practices at the beginning of the school year. Some of the students also are able to develop solutions that involve the conceptual creation of units of 10 and 1. However, when they do so, they are obliged to explain and justify their interpretations of number words and numerals. Later in the school year, solutions based on such interpretations are taken as self-evident by the classroom community. The activity of interpreting number words and numerals in this way has become an established mathematical practice that no longer stands in need of justification. From the students' point of view, numbers simply are composed of 10s and 1s—it is a mathematical truth.

This illustration from the second-grade classrooms describes a global shift in classroom mathematical practices that occurred over a period of several weeks. An example of a detailed analysis of evolving classroom practices can be found in Cobb et al. (in press). In general, an analysis of this type documents instructional sequences as they are realized in interaction in the classroom, and therefore, draws together the two general aspects of developmental research: instructional development and classroom-based research (see FIG. 12.1). This type of analysis also bears directly on the issue of accounting for mathematical learning as it occurs in the

social context of the classroom. Viewed against the background of classroom social and sociomathematical norms, the mathematical practices established by the classroom community can be seen to constitute the immediate local situations of the students' mathematical development. Consequently, in identifying sequences of such practices, the analysis documents the evolving social situations in which students participate and learn. Individual students' mathematical conceptions and activities are taken as the psychological correlates of these practices, and the relation between them is considered to be reflexive (see Table 12.1).

Summary. The framework that I have outlined illustrates one way of organizing and structuring analyses of classroom activities and events. The primary function of such a framework is to provide a way of coping with the messiness and complexity of classroom life. By definition, a framework influences to a considerable extent the issues that are seen as significant and problematic when a teaching experiment is in progress. In our case, for example, it is not surprising that sociomathematical norms became an explicit focus of attention in the daily debriefing sessions and weekly meetings held during a recently completed teaching experiment. In a nontrivial sense, the interpretive framework is an integral aspect of the reality with which the research team is experimenting. As a consequence, the importance of attempting to articulate provisional theoretical constructs that might inform the interpretation of classroom events cannot be overemphasized.

Retrospective Analysis

Thus far, the discussion has focused on both the planning of a teaching experiment and the ongoing experimentation in the classroom that is central to the methodology.[7] A third aspect of the methodology concerns the retrospective analysis of the entire data set collected during the experiment. One of the primary aims of this analysis is to place classroom events

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[7] It is this process of ongoing experimentation inherent in the daily microcycles that differentiates the classroom teaching experiment from traditional, formative-evolution designs in which the research team starts with ready-made innovations, implements them in the classroom, and assesses their effectiveness.

in a broader theoretical context, thereby framing them as paradigmatic cases of more encompassing phenomena. In this regard, the retrospective analysis can be contrasted with the analysis conducted while the experiment is in progress in that, typically, the latter is concerned with issues that relate directly to the goal of supporting the mathematical development of the participating students. For example, in the course of the teaching experiment reported by M. Simon (1995), the ongoing analysis appears to have focused on the immediate goal of helping students develop an understanding of the multiplicative relationship involved in evaluating the area of a rectangle. However, in the retrospective analysis, classroom events were considered to be paradigmatic of instructional processes guided by a constructivist view of learning. The goal of this analysis, therefore, was to develop a model of teaching that is compatible with constructivism. Similarly, in a first-grade teaching experiment that I and my colleagues conducted recently, the immediate goal was to support the students' development of increasingly sophisticated arithmetical conceptions. To this end, we modified and refined tentative instructional sequences compatible with RME while the experiment was in progress. As a result, the sequences that were enacted in the classroom involved conjectures about the role that modeling and symbolizing might play in the children's mathematical development. One of the retrospective analyses that has been completed thus far focuses on this issue and treats classroom events as paradigmatic situations in which to develop a theoretical account of modeling, symbolizing, and using cultural tools (Cobb et al., in press).

It is apparent from the prior discussion of experimenting in the classroom that the day-to-day concern of supporting the participating students' mathematical development has a theoretical aspect. However, this concern is located in the immediate context of pedagogical judgment. In conducting a retrospective analysis, the research team steps back and reflects on its activity of experimenting in the classroom. Therefore, interpretations of particular events can be located both retrospectively and prospectively in the unfolding stream of classroom activity (cf. Steffe & Thompson, chap. 13, this volume). As a consequence, theoretical analyses grow out of and yet remain grounded in the practice of doing classroom-based developmental research. Further, in the longer term, the research agenda evolves as theoretical analyses completed in one experiment feed forward to inform future experiments (cf. Yackel, 1995).

GENERALIZABILITY, TRUSTWORTHINESS, AND COMMENSURABILITY

In discussing specific methodological issues, I find it useful to distinguish between two types of products developed in the course of teaching experiments: theoretical analyses and instructional innovations. I consider each in turn.

Theoretical Analyses

A theoretical analysis is the result of a complex, purposeful, problem solving process. Therefore, one would not expect that different researchers would develop similar theoretical constructs when analyzing a data set created in the course of a teaching experiment.[8] This implies that the notion of replicability is not relevant in this context. Following Atkinson, Delamont, and Hammersley (1988), I suggest, instead, that the relevant criteria are those of the generalizability and the trustworthiness of the analysis.

The issue of generalizability was touched on when discussing retrospective analyses. There, the importance of viewing classroom events as paradigmatic of broader phenomena was emphasized. It is this treatment of classroom activities and events as exemplars or prototypes that gives rise to generalizability. Of course, this is not generalization in the traditional sense that the characteristics of particular cases are either ignored or treated as interchangeable members of the set to which assertions are claimed to apply. Instead, the theoretical analysis developed when coming to understand one case is deemed to be relevant when interpreting other cases. Thus, what is generalized is a way of interpreting and acting that preserves the specific characteristics of individual cases. For example, I and my colleagues conjecture that much of what we learned when analyzing first-graders' modeling can inform analyses of other students' mathematical learning in a wide range of classroom situations, including those that involve the intensive use of technology. It is this quest for generalizability that distinguishes

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[8] Instances in which a group of researchers develops a range of differing analyses of a single data set can be of interest in their own right (cf. Cobb & Bauersfeld, 1995).

analyses whose primary goal is to assess a particular instructional innovation from those whose goal is the development of theory that can feed forward to guide future research and the development of activities.

Whereas generalizability is associated closely with the notion of paradigm, trustworthiness is concerned with the reasonableness and justifiability of inferences and assertions. This notion of trustworthiness acknowledges that a range of plausible analyses might be made of a given data set for a variety of different purposes. The issue at hand is, therefore, that of the credibility of an analysis. The most important consideration in this regard is the extent to which the analysis of the longitudinal data set is both systematic and thorough. This is an extremely pressing issue given that large sets of videorecordings and transcripts are generated in the course of a teaching experiment. What is required is a systematic analytical approach in which provisional claims and conjectures are open to continual refutation. Cobb and Whitenack (1996) illustrated one such approach that draws heavily on B. G. Glaser and A. L. Strauss's (1967) constant comparative method. Irrespective of the specific approach adopted, it is important to document all phases of the analysis process, including the refining and refuting of initial conjectures. Then, final claims and assertions can be justified by backtracking through the various levels of the analysis, if necessary to the videorecordings and transcripts. This documentation of the research team's learning process provides an empirical grounding for the analysis (Gravemeijer, 1995). Further, it provides a means of differentiating systematic analyses in which sample episodes are used to illustrate general assertions from questionable analyses in which a few, possibly atypical, episodes are used to support unsubstantiated claims. Additional criteria that enhance the trustworthiness of an analysis include both the extent to which it has been critiqued by other researchers and the extent to which it derives from a prolonged engagement with students and teachers (S. J. Taylor & Bogdan, 1984). Typically, this latter criterion is satisfied in the case of classroom teaching experiments and constitutes a strength of the methodology.

Instructional Innovations

A central assumption of developmental research is that instructional innovations developed in the course of a classroom teaching experiment can lead to productive patterns of learning when they are enacted in other classrooms. However, as we know only too well, the history of research in education in general, and in mathematics education in particular, is replete with more than its share of disparate and often irreconcilable findings. From the emergent perspective, a primary source of difficulty is that the independent variables of traditional

experimental research are relatively superficial and have little to do with either context or meaning. We have seen that in the emergent view, students are considered to perceive, act, and learn as they participate in the self-organization of a system that is larger than themselves—the community of practice established in the classroom. In such an approach, learning is characterized as "an aspect of self-organization, not just of the human organism as a biological system, but of ecosocial systems in which the organism functions as a human being" (Lemke, in press). It is this participation in an evolving community of practice that is not addressed by traditional experimental research.

In my view, the primary concern is not so much that past findings have been disparate as that they have been irreconcilable. Hence, it has not been possible to account for the differences in findings when different groups of students receive supposedly the same instructional treatment. In contrast to traditional experimental research, the challenge from the emergent perspective is not that of replicating instructional innovations by ensuring that they are enacted in precisely the same way in different classrooms. The conception of teachers as professionals who adjust their plans continually on the basis of ongoing assessments of individual and collective activity in the classroom would suggest that complete replicability is neither desirable nor, perhaps, possible (cf. Ball, 1993b; M. Simon, 1995). Instead, the challenge, as it is construed from the emergent perspective, is to develop ways of analyzing innovations that make their realization in different classrooms commensurable. The interpretive framework that I have outlined evolved in the context of developmental research and, therefore, constitutes one possible way to organize such analyses. The central point is not, however, that others should use this particular framework. Instead, it is to emphasize the potential contributions of interpretive frameworks that are concerned with context and meaning. Frameworks of this type can support greater precision in developmental research by making it possible to compare, contrast, and relate different enactments of innovations. In the case of the framework outlined in this chapter, for example, an analysis of the mathematical practices established as an instructional sequence is enacted in a particular classroom documents that sequence as it is realized in interaction. Viewed against the background of classroom social and sociomathematical norms, the instructional sequence as enacted by a particular classroom community also can be seen to constitute the evolving social situation in which the students' mathematical development occurred. Consequently, an analysis of two different enactments of the same instructional sequence conducted in terms of constructs such as classroom social norms, sociomathematical norms, and classroom mathematical practices

involves a comparison of the evolving social worlds in which the two groups of students participated. Such an analysis, therefore, makes different enactments of the same innovation commensurable. In addition, it emphasizes context and meaning by bringing to the fore the practices in which the students participated as they reorganized their mathematical activity. We contend that an approach of this type, in which commensurability is based on context and meaning, can facilitate disciplined systematic inquiry into reform and change that embraces the messiness and complexity of the classroom.

COLLABORATING WITH TEACHERS

The type of classroom teaching experiment in which researchers collaborate with one or more teachers can be contrasted with that in which a researcher also acts as the teacher. The close relationship between these two approaches is indicated by the frequent references I have made to an experiment reported by M. Simon (1995), in which he acted as the teacher. The decision of whether or not to act as the teacher involves a trade-off. On the one hand, in experiments conducted in collaboration with a teacher, the researcher typically learns something about the process by which teachers reorganize their instructional practices even if this is not an explicit focus of investigation. Such insights are of immediate pragmatic relevance in that they can inform ongoing teacher development efforts. On the other hand, researchers who collaborate with teachers probably have less flexibility in pursuing particular visions of reform than do researchers who act as teachers. In the latter case, the researcher can follow up immediately on his or her own conjectures and intuitions in the classroom. In contrast, the role of a researcher who collaborates with a teacher is that of a leader in a local pedagogical community comprising the research and development team. One of his or her primary responsibilities is to guide the development of this community as it seeks to arrive at taken-as-shared decisions and judgments. Thus, whereas a researcher who serves as the teacher can act solely on the basis of his or her own judgments, a researcher who collaborates with a teacher can be effective only by acting as a member of a local community. In the former case, the researcher acts with fewer constraints, but, in the latter case, the context of the teaching experiment is closer to that in which reform must take place eventually. Consequently, researchers who collaborate with teachers accept what can be called realistic constraints as they explore what might be possible in students' mathematics education.

With regard to the process of conducting a teaching experiment in collaboration with a teacher, the overriding concern should be that of establishing an effective basis for communication so that the teacher and the researchers constitute a pedagogical community united by a common purpose. The possibility of developing such a basis for communication should be considered very seriously when deciding whether or not to collaborate with particular teachers. In our experience, we have found it critical to identify initial common ground from which an adequate basis might evolve. These taken-as-shared assumptions and beliefs could concern what the teacher and the researchers value mathematically, or they could involve general views about what constitutes students' intellectual and social welfare in school. As a next step, usually, an extensive series of interactions is necessary before the teaching experiment begins so that the teacher and the researchers can understand each other's viewpoints. These interactions, which should be negotiated mutually, could include mathematical problem solving, videorecorded interviews conducted by the teacher with his or her students, or pilot work conducted in the teacher's classroom in order to provide a context in which to discuss interpretations of particular events. The overall goal is that the teacher and the researchers will develop a taken-as-shared understanding of the rationale for and intent of the agreed-upon innovation before the teaching experiment begins.

Once the experiment is in progress, daily debriefing sessions and weekly meetings provide occasions in which to develop taken-as-shared interpretations of what is happening in the classroom. In our experience, the discussions in these meetings can be far-ranging and might focus on the quality of an individual student's mathematical activity, the nature of classroom norms and mathematical practices, or the planning of instructional activities. As a general rule, we have found it helpful to draw on our understanding of learning as it occurs in a social context to guide our interactions with collaborating teachers (Yackel, 1995). In doing so, our primary concern has been to support the teachers' development while simultaneously learning from them rather than to ensure that they act in accord with our personal interpretations and judgments. This attempt to be consistent when conducting teaching experiments stems from the concern that collaborating teachers might assume that their role is merely to translate researchers' decisions and judgments into practice. However, it is possible to explore the prospects for reform in collaboration with teachers only if they develop personally justifiable forms of practice as they participate in a teaching experiment. Therefore, the highest priority should be given to establishing with the collaborating teachers relationships that are based on mutual respect and trust.

CONCLUSION

In this chapter, I have discussed the strengths of the methodology of the classroom teaching experiment. The most important of these derives from the researchers' participation in a collaborative team that is responsible for the quality of students' mathematical activity on a daily basis. This prolonged engagement with teachers and students provides an experiential grounding for theoretical developments that can inform practice. Throughout the discussion, I have emphasized that the teaching experiment methodology has emerged from attempts to address a range of problems and issues, including those of reform at the classroom level. In these concluding remarks, I consider situations in which other methodologies might be more appropriate.

When conducting a classroom teaching experiment, a recurring challenge is that of documenting in detail the quality of individual students' mathematical reasoning. A number of techniques can be used to alleviate this difficulty. They include the regular use of classroom tasks and activities designed specifically to solicit informative records of students' mathematical interpretations. In addition, interviews can be conducted with selected students immediately after classroom sessions, and interventions can be made on camera to ask clarifying questions or to pose impromptu tasks. However, even when these techniques are used, researchers conducting a classroom teaching experiment cannot maintain a continuous focus on the mathematical activity of all of the participating students. In my view, the constructivist teaching experiment developed by Steffe and his colleagues is a more appropriate methodology when the primary concern is to analyze the psychological processes by which individual students reorganize their activity (cf. Steffe & Thompson, chap. 13, this volume). I would observe only that this methodology does not provide a window into students' mathematical cognitions independent of situation and purpose. Instead, it provides a means of investigating the conceptual developments that students make while interacting with the researcher. From the emergent perspective, it is important to document the social situation of students' development even in the case of a series of one-on-one teaching sessions. Accordingly, the examination of these sessions should involve the coordination of a psychological analysis of the students' activity with a social analysis of the relationship established jointly by the researcher and the student.

A second set of issues for which the classroom teaching experiment is not well suited concerns the broader sociopolitical context of reform. In the type of teaching experiment that I have described, explanations of teachers' and students' activities typically are formulated in

terms of processes located at the classroom level and focus on individual interpretations and face-to-face interactions and discourse. These explanations do not make reference to students' and teachers' participation in practices located outside the classroom at the school and community levels. A variety of other methodologies, including ethnographies, may be more appropriate for investigations that focus on cultural diversity and the restructuring of the school as it relates to reform in mathematics education (cf. Doerr & Tinto, chap. 15, this volume; Moschkovich & Brenner, chap. 17, this volume).

As is the case with any methodology, the classroom teaching experiment allows researchers to address some issues better than others. Its primary contribution is in allowing researchers to investigate the implications of reform as they play out in interactions between teachers and students in classrooms. Throughout this chapter, I have drawn on my own and my colleagues' experience of collaborating with teachers to clarify what is involved in conducting classroom teaching experiments that can inform ongoing reform efforts. In the last analysis, the relevance of the methodology will rest on the extent to which it continues to provide such guidance.

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